THE STORY OF ELECTRICITY

STORIES OF SCIENCE

Uniform with this Volume

THE STORY OF THE ATOM
By W. F. F. SHEARCROFT

In Preparation

THE STORY OF MATHEMATICS
THE STORY OF GEOLOGY
THE STORY OF PLANT LIFE
THE STORY OF THE STARS
THE STORY OF MAN

THE STORY OF ELECTRICITY

FROM THALES TO EINSTEIN

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PREFACE

The very hearty welcome accorded my *Story of the Atom*, both by reader and reviewer, has suggested the continuance of the series. There is an obvious demand for the information that these books contain. Our daily life is coming more and more closely into touch with the applications of science, and to take an intelligent interest in what is happening in our midst makes an acquaintance with the main outlines of progress a necessity. Few of us have the leisure to wander very far out of our own particular field of specialisation, and so we welcome efforts that will give this necessary information, provided we can be assured that accuracy has not been sacrificed to startling phraseology.

The schoolmaster has recognised that these wide-flung views of scientific progress make an interesting appeal to his pupils. Such views are often crowded out of the classroom by the stern realities of examination demands; but such a loss is recognised as detrimental to both pupil and subject.

The Story of Electricity will, perhaps, have a wider appeal than any other, for do we not live in an age of electricity? Not only does it work for us in our factories, but it contributes to our comfort in the home, carries us safely and swiftly on our journeys, and is now making large demands on our amusements.

The teacher, as a purveyor of knowledge, has

always to acknowledge gratefully the debt he owes to the worker in the laboratory, thanks which I gladly give. At the same time I would express my thanks and appreciation for the criticism and suggestions that have helped towards this venture, and cordially invite the continuance of such help from my readers.

W. F. F. S.

PETERBOROUGH,
June, 1925.

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THE STORY OF ELECTRICITY

CHAPTER I

WHAT IS ELECTRICITY?

Black night broods over the deep; the sky thunders, and the air sparkles with innumerable fires. VIRGIL.

When the thunderbolt strikes one man it is not one man only that it fills with terror. OVID.

He has loosed the fateful lightning of his terrible swift sword. HOWE.

Knowledge has clipped the lightning's wings and mewed it up to some purpose. TUPPER.

WE are always surprised that it is the simple and familiar things in life about which we know least. The questions that a small child asks are just those that the learned are unable to answer. The ordinary operations of everyday routine, that we perform thoughtlessly, yet with surprising efficiency, are often the operations that puzzle the best brains of to-day and have puzzled the best brains of the past.

The truth of this statement is strikingly illustrated by the subject of Electricity. To-day we are all electricians of a kind. We switch on the light; we use the telephone; we listen-in to the wireless concert, having first tuned in our set; we travel in electric lifts; our trams and our trains are run by electricity, and at every touch and turn

electricity enters into our lives. Our engineers can control this mighty force, and harness it to the workshops of the civilised world; our mathematicians can calculate and forecast its habits; our physicists can tell strange tales of its structure —and yet the child's question that heads this chapter is still awaiting an answer. Engineers, mathematicians, and physicists alike have to borrow from the politician and say "Wait and see!"

Such ignorance is all the more surprising when we consider that electrical manifestations have impressed mankind more markedly than any other of the so-called forces of nature. Even primitive man conquered earth, air, fire and water. He climbed the rocky heights, braved the hurricane, stole fire from the Gods, and sailed the mighty deep. But, when Jove hurled his thunderbolts, the rude savage bowed a submissive head and slunk to the innermost recesses of his cave, cowering like a frightened puppy. Vast civilisations arose, countless men of science studied the world and its problems, feats of engineering that stagger us even now were performed, yet there is no trace of the use of electricity or any knowledge of it other than a wholesome fear of its consequences. It would almost seem as if the paralysing fear of the lightning had extended to the mind, for this was the last of the great natural phenomena to be studied.

It is only in comparatively recent times that man even began to brave this elemental power.

It is less than two hundred years ago that Franklin tamed the lightning flash and made it dance to the tune he called in a solitary little hut in what is now the city of Philadelphia.

Since the days of Franklin we have made much progress. From simplicity we have passed to a complexity of information and then back almost to the extreme of simplicity; but still that simple little question remains unanswered. We do not despair of ever finding an answer; in the fullness of time it will come. We know, now, much of the structure of electricity, we can understand its ways, but what it is we leave to the future.

We shall find that our story is like a river. It will start as a tiny trickle that gathers volume as it flows down the slopes of time. It will gather to itself the tributary streams of other sciences and finish as a broad estuary opening into the sea of knowledge.

CHAPTER II

EARLIEST HISTORY

THE history of almost every other branch of science has beginnings reaching back as far as we can trace the history of mankind. The fundamental atom of the chemists appears in early Greek philosophies. Mathematics and astronomy were established sciences while yet civilisation was young; but of electricity there is nothing, nothing but the picturesque language of the poets depicting the horrors of lightning.

Efforts have been made to trace a reference to electricity in the old Greek myth of fire stolen from the heavens. It has been suggested that this legend is the first record of man's conquest of the lightning flash. Such an interpretation is far too fanciful to stand examination. The minds that recorded the vague speculations of other sciences, the minds that calculated the motions of the heavenly bodies would not have missed an event of such importance as this. The truth would have been dragged out of the myth, and its consequences might have altered the whole history of the world.

There are records as far back as 600 B.C. that a piece of amber when rubbed acquired the property of attracting small objects such as pieces of straw or small feathers, a fact that we now know is an electrical manifestation. The Chinese, in far distant days, were acquainted with the

natural magnet, and used it to guide their armies and steer their ships. No attempt to explain these phenomena was made, and most certainly they were never conceived as being related to the lightning flash or to one another. They were isolated observations, the one a curiosity and the other a useful adjunct to a thoughtful race, the knowledge and use of which slowly spread to the Western nations.

We have to date the real birth of our science two thousand years later than Thales' observation of the peculiar property of amber. At this later date we find a Court physician of Queen Elizabeth, Gilbert by name, extending the observations in a scientific fashion. Stimulated by the new era of true scientific research that began in these days, Gilbert made his experiments. He found that numerous substances acquired this property of being able to attract light objects when they were rubbed. From the Greek word for amber he introduced the name *electricity*. The bodies that were rubbed and were then able to attract other small bodies were said to be "electrified." He also carefully examined the phenomena of magnetism and recorded his results. No attempt, however, was made to offer any explanation of these results.

A century passed before the next step was taken, when the discovery was made that the rubbing was not always attended with identical results. The "electrification" produced by friction on one class of substance was different

from that produced on another class of substance. When resinous substances, such as amber, were rubbed, one kind of electrification was produced; when vitreous substances, such as glass, were rubbed, another kind of electrification was produced.

This observation, which we shall consider more in detail in the next chapter, led to the formation of the first theory which was stated in the middle of the eighteenth century. Certainly, this theory was very much akin to the scientific theories of the ancients, in that it was not supported by any evidence in its favour. It was a pure guess, but, we may add, a necessary guess.

In its early stages a theory, or more correctly an hypothesis, is always a challenge. We may accept a statement of an observation without question, especially if the statement originates from a person of standing. A mere statement, provided it is not obviously absurd, rouses no spirit of controversy. Once, however, the statement is followed by an attempted explanation or theory, we all claim the right to criticise. We may be unable to repeat the observation for lack of opportunity or lack of skill or any other cause, but we feel that the mental operation of giving an explanation is common ground. Such criticism is usually, at first, either flat denial or sarcastic humour, but it serves the purpose of stimulating interest, and the search for information to support the one side or the other is at once undertaken.

CHAPTER III

THE FIRST THEORY

Electrical manifestations were obtained when a number of different substances were rubbed, and these manifestations were of two kinds. This difference in the kind of electrification must be considered first. It may be inconvenient to make experiments with the body that is actually rubbed, but the "electrification" can be easily transferred to other and more convenient bodies by simple contact. A small ball of pith makes a very convenient test specimen, and it may be easily isolated by suspending it by a thread of silk, as indicated in the diagram.

If a piece of sulphur be rubbed with a fur, and the pith ball touched with the sulphur, some of the "electrification" on the sulphur is transferred to the ball. Immediately this is done we find that the pith ball is no longer attracted by the electrified sulphur but is repelled instead, as shown in the diagram.

We may repeat the experiment very simply, as we read, by using the vulcanite body of a fountain pen in place of the sulphur, a coat sleeve will do for the rubber, and a tiny screw of paper hung up by a cotton thread will serve in place of the pith ball. The repulsion that takes place we are bound to attribute to the two charges, one on the sulphur and one on the pith ball. Obviously, they must be similar charges, as both

are derived from the same rubbed body. This repulsion we find to be general whenever we allow two similar charges to approach one another.

If we now take a piece of glass and rub it with silk, then the glass becomes charged. If we bring the glass near the pith ball, charged by the sulphur, then attraction takes place. Obviously the charge on the glass differs from that on

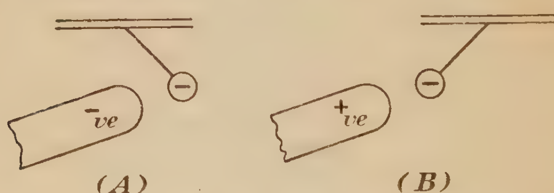

FIG. 1.—(*A*) Negatively charged pith ball repelled by negative charge on sulphur.
(*B*) Same pith ball attracted by positive charge on glass.

the sulphur. We may sum up these differences by saying that *similar electric charges repel one another but unlike charges attract.*

The two kinds of "electrification" we have noted are typified by the charge on glass, when rubbed by silk, and known as *vitreous electricity*, and the charge on sulphur, when rubbed by fur, and known as *resinous electricity*. These rather cumbrous names were very soon replaced by the words *positive* and *negative*. The glass was said to be positively charged and the sulphur negatively charged.

It was further noted that not only did the body that was rubbed become charged during the process but that the rubber also assumed a charge of the opposite nature.

It is almost obvious that at this stage a theory should arise, and we can go even a step further and say that the theory that did arise was the natural one. By vigorous rubbing, neutral bodies became charged; nothing was added during the process, and so what appeared must have been there at the start. Along these lines the mind of Franklin conceived the idea of an "electrical fire," a kind of liquid that permeated all material bodies. He imagined that matter, as we usually find it in a neutral state, contained a normal amount of this fluid. If by any means a piece of matter could be made to contain more or less than this normal amount, then it exhibited electrical properties. If the amount was above the normal then the body was positively charged, if less than the normal, then negatively charged.

Here at last was a theory around which discussion could take place. It was possible to think about the subject, and not just state the facts observed. Franklin speculated as to the nature of this electrical fire and his conclusions may be stated in his own oft-quoted words: "The electrical matter consists of particles extremely subtle, since it can permeate common matter, even the densest, with such freedom and ease as not to receive any appreciable resistance."

We may marvel at this conclusion in the light

of present-day knowledge, but we must remember that it was no more than a wild speculation. Franklin produced no evidence in its favour. It was the product of his mind only. The theory is known as the *Single Fluid Theory*, and as far as it went it did prove satisfactory. Its consequences, however, led to a difficulty that was greater than the thinkers of those days could tackle and so the theory was short-lived.

The difficulty arose in this fashion. Two negatively charged bodies repelled one another. Negatively charged bodies, however, were, according to the theory, matter which was deficient in the electrical fluid. The greater the deficiency the more was the repulsion. If this idea is carried to its logical conclusion, there should be a stage when the bodies were robbed of all the electrical fluid and were just matter alone. But then, most obviously, matter would be self-repellent, as the repulsion would go on increasing and increasing as the amount of fluid got less and less. Hence adherence to the Single Fluid Theory necessitated the bestowing on matter a new property of self-repulsion.

Such an idea was too much for those days. Matter was matter as it was found. At times it might be associated with some electrical fluid, but it could not suddenly be endowed with new properties—at least not at the bidding of a theory. It was much simpler to change the theory, which was immediately done.

A new theory was devised which postulated two electrical fluids. One of these possessed the property of conferring positive charges on matter and the other negative charges. The neutral or normal state of matter was either matter without these liquids, or matter in which the opposing tendencies of the two liquids mutually cancelled one another. An excess of either manifested itself by the exhibition of the corresponding electrical phenomena.

This conception succeeded in shutting electricity up in a water-tight compartment, and leaving matter unaltered. One could think of electricity as isolated, and of matter alone, and any connection between the two, other than association, was not necessary.

The *Two Fluid Theory* was provocative of much good work, and, as we reach the end of the eighteenth century, we find rough measurements of the magnitude of electric charges have been made. It is definitely proved that the lightning flash can produce exactly similar effects to those given by the charges produced by friction. All forms of matter were found to be capable of being electrified by friction, the only necessary condition being one of insulation, so that the charges produced do not immediately leak away along the supports. It is also known that an electric charge will pass from one place to another along wires made of certain materials, but very little attention was given to this effect.

It was noticed that electrical charges could be

produced by other means than friction. The heating of metals under certain conditions yielded small charges, a few animals, such as the Electric Eel, were capable of manufacturing charges. The only practical method of getting a charge, however, was by means of friction. Quaint and cumbrous machines were constructed for the more efficient production by friction. In these, the rubbed body was rapidly rotated by hand so that it rubbed against a stationary rubber. The charges, from the rubber and the rubbed body, were then collected on knobs.

So far the whole subject appeared to the average man as a series of rather more than usually interesting tricks. The frictional machines generated charges that could be made to perform some very striking experiments, but there was very little that appeared of practical value. Certainly Franklin had based his invention of a lightning conductor on his researches, an invention of great importance. It was realised, however, that the research worker was dealing with mighty forces, but how such forces were to be generated in quantities sufficient for use, or how they were to be controlled when produced, did not appear at this stage.

CHAPTER IV

GALVANISM

Up to the end of the eighteenth century the only method of producing a supply of electricity was by the use of cumbrous frictional machines. Following up some observations made by Galvani, Volta was able in 1779 to construct his famous "pile." This consisted of a number of alternate pieces of metal connected together, but separated by pieces of flannel soaked in dilute acid. From the end-pieces of the pile, wires led away, and the ends of these wires were found to possess, one a positive charge and the other a negative charge. The arrangement is illustrated in the diagram.

Here at last was a convenient method of producing a supply of electricity, which attracted immediate attention. Arrangements of such a nature were made containing many hundreds of pairs of plate. With these larger "piles" or batteries, sparks were obtained across the gap between the terminal wires and all the other phenomena of the frictional machines reproduced. It was thus proved that the "pile" produced electricity identical with that produced by friction.

When the terminal wires were joined, then a continuous action took place and electricity "flowed" along the wire. This was not unexpected, as similar "flowing" had been observed before. Attention was directed, however, more prominently than before to these "currents" of

electricity and this manifestation was called *Galvanism* or *Voltaic electricity*.

The "pile" invented by Volta is the forerunner of the modern electric cell and battery. The many varieties of this, which now appear on the market, are based on the same principle as that of the "pile." In all cases there are two dissimilar substances in contact with a third. Under these conditions chemical action takes place and electricity is produced as a result of this action.

FIG. 2.—Diagram of Voltaic "Pile"

In an exactly similar way heat is produced when a piece of wood undergoes the chemical action that we call burning. It is a question of arranging the chemical action to take place under certain definite conditions.

The simplest possible electrical cell consists of a plate of copper and a plate of zinc, both dipping into dilute sulphuric acid. Under these conditions the copper plate will acquire a positive charge and the zinc plate a negative one. It is important to emphasise that these charges are identical with those produced by the old frictional machines.

They differ only as regards what is known as *potential.*

We may best approach the meaning of this word potential by considering what occurs when we connect the two plates of our simple cell by means of a wire. An electric current immediately begins to "flow" around the circuit. It is customary to consider that positive electricity "flows" from the positive plate along the wire to the negative plate. As a matter of fact it does not much matter which way we consider the "flow" to take place, but the custom above is established and so we will use it.

If we join the two plates by means of a piece of wood, no current will "flow," and, further, as we vary the material by which the plates are joined, we find that some are better conductors than others. We can consider that all offer some resistance to the "flow." We may seek an analogy in the flow of water through a pipe which is filled with some material. It will be easier for the water to flow through the pipe if it is packed with lead shot, than if it is choked with fine sand. We can see, however, that the rate of flow of the water will, in any case, depend also upon the pressure at which the water is supplied. Water pressure we express as a "head of water of so many feet." The head of water represents the driving power behind the stream.

In a similar way we may think of an electrical pressure which drives the electricity through the conductor. This electrical pressure is measured

as potential, and the unit of potential is called a *volt*. We are not concerned here with how potential is measured, but it is necessary to realise what it is that volts measure.

In our cell we have two charged plates which are maintained, by the chemical action taking place in the cell, at different potentials. The difference between the potential of the copper plate and the zinc plate is a measure of the driving force behind the electric current that "flows" when the plates are connected by a conductor. In the simple cell, we are considering, this potential difference will be about one volt.

The difference of potential between the knobs on a frictional machine, which bear opposite charges in the same way as the plates in the cell, will be about one hundred thousand volts. By combining many cells the difference in potential between the copper plate in the first and the zinc plate in the last can be made as large as we like.

The simple cell, as indicated above, suffers from one great disadvantage. For reasons into which we need not enter, it very soon "runs down," and the current of electricity ceases. The modifications of the modern cell are devised to overcome this running down, but the main principle is the same—a supply of electricity is manufactured as a result of the chemical action that takes place, the plates of the cell being maintained at a constant potential difference as long as the materials of the cell are not exhausted.

The charges that have been considered so far

have been stationary charges associated with some insulated conductor. We must now turn our attention to these new dynamical manifestations of electricity and investigate the effects of an electric current.

CHAPTER V

CURRENT EFFECTS

It was discovered by the examination of these currents that the passage of electricity through a conductor was attended by heating effects. The conductor became heated in the process. This discovery laid the foundation for all our modern lighting by electricity in which some form of conductor is made so hot as to give out light. As we know, we also use electricity for heating purposes. Electric furnaces, electric stoves for cooking, electric radiators and many other forms of convenient heating are commonly in use nowadays.

The passage of electricity through a number of substances was found to produce chemical actions. Very soon after the discovery of Volta, it was possible to isolate the hitherto unknown metals sodium and potassium from their compounds by means of the electric current, and the beginning was made of an industry that to-day is of immense importance. We need only mention the electroplating industry and the isolation and purification of some common metals to indicate the importance of this chemical effect of the electric current.

More important still, from our point of view, was the discovery made by Oersted in 1820, when he was able to announce that a current of electricity flowing through a wire had an effect on a magnet.

To this effect we must give more detailed treatment, as it is fundamental to the progress of our

story. We all have memories of simple little experiments with a magnet. We know that a magnet will pick up small pieces of iron from the table, and if we float the piece of iron on a cork in a dish of water, then we can make the iron follow the magnet, without the magnet ever touching the piece of iron. We sum this up by saying that the magnet "attracts" the iron, although we might be in difficulties if we tried to define precisely what we meant by that word "attracts." We can, however, recognise that in the neighbourhood of a magnet there is a space within which pieces of iron are attracted. The attraction may not be enough to make them move in any particular case, but it is there, whether movement takes place or not.

We also know that a magnet supported so that it is free to swing, always takes up a definite position so that one end is pointing towards the north. It is always one particular end that points to the north, so that one end of a magnet is different from the other. We call the ends of a magnet its poles, and the one which points to the north is called the *north-seeking pole*. This behaviour is, of course, the principle on which our compasses work.

If we support two magnets side by side, so that they are free to move, then we find that one north-seeking pole repels another, and that a north-seeking pole attracts a south-seeking pole. *Like poles repel, unlike poles attract*, which reminds us of the attraction and repulsion of electric charges.

Although it is impossible to so magnetise a piece

of steel that it possesses one pole only, we can, in thought, isolate a magnetic pole. Such an isolated north-seeking pole would, if placed in the neighbourhood of a magnet, be attracted by one pole of the magnet and repelled by the other. If the little pole were free to move it would travel towards the south-seeking pole of the magnet, along a path determined by the action of the two poles.

We could use such a pole to test for the presence of a magnet. If no magnet were near then the test-pole would remain stationary. Directly it came within the sphere of influence of a magnet it would commence to move. The sphere of influence of a magnet is called the *field of the magnet*. Around every magnet is such a field which gets weaker and weaker the farther away from the magnet we move.

Oersted's experiments demonstrated that such a magnetic field existed in the neighbourhood of an electric current "flowing" through a conductor. A small compass needle placed near a current of electricity is deflected out of its north and south positions.

We must now consider a little more in detail what is happening in a magnetic field when the magnet is "attracting" a piece of iron. If we place a magnet on the table, we say that it is surrounded by a magnetic field. If into this field we introduce a piece of soft iron then the iron is "attracted" by the magnet, or in other words the iron is influenced by the magnetic field. If we turn our attention to the piece of iron we find, and we

can easily demonstrate experimentally, that as a result of this influence the piece of iron itself has become a magnet. It acquires magnetic properties temporarily, only so long as it remains in the magnetic field. If the original magnet is removed, then the iron at once returns to its unmagnetised state.

This process is called *magnetic induction.* It should be noticed that this is only a convenient name for the process, it is not an explanation of what is happening.

If, then, an electric current is able to have an influence on a magnet, it must be surrounded by a magnetic field, and that magnetic field should be able to induce magnetism in a piece of iron. Experiment shows that this induction will take place. If a wire, carrying a current, is wrapped round a piece of iron then, as long as the current is "flowing," the iron acts as a magnet. Such an arrangement is known as an electro-magnet.

At the time these discoveries were made they caused immense excitement, as they indicated a very close connection between electricity and magnetism; and dimly, at first, it was seen that they forecasted wonderful practical applications.

CHAPTER VI

FURTHER WORK ON CURRENT EFFECTS

THE next step in the progress of our story is associated with the name of Faraday. His work took two main directions which, as a matter of fact, were mutually contradictory.

Faraday reached the study of electricity after investigating the phenomena of magnetism more thoroughly than had been done before. He pondered over the action of a magnet on a piece of iron at some distance from it. How was it possible for this influence to be communicated across the intervening space? He examined this space and found that if he scattered iron filings in the neighbourhood of a magnet, they arranged themselves in a definite pattern. They always took up positions along lines that stretched from one pole to another of an opposite nature. These lines he could see would be the paths of a test-pole, such as we have imagined in the previous chapter, free to move in the magnetic field. In this way he came to picture a magnetic field as mapped out into these "lines of force."

It is only necessary for us to note that this conception directed attention away from the magnet to the field that surrounded it. Magnetic effects were investigated and thought of as being in this field. Around a magnet existed a state that did not exist around unmagnetised matter.

It was more or less obvious that these ideas

should be carried over into a consideration of the magnetic effects associated with a current of electricity. The current produced a similar state in surrounding space as did the magnet. The conductor carrying the current was the centre of two fields, a magnetic field, producing effects similar to a magnet, and an electric field that produced other effects.

Faraday set about an investigation of this electric field. He mapped its attractions and repulsions in lines of force, as he had done for magnetic fields. Along these electrical lines of force would travel an isolated small charge of electricity, in the same way that an isolated pole travels along the magnetic lines of force. Electric and magnetic fields were considered to be completely described when the number and direction of their lines of force were known.

This investigation of fields of force resulted in a discovery which had far-reaching results. It was found that not only did a moving current of electricity produce magnetic effects, but a moving magnet could also produce electrical effects. If a magnet be moved in the neighbourhood of a suitably arranged conductor, then a current of electricity is produced in the conductor. This discovery paved the way for a wonderful practical advance, as it indicated a new method of obtaining supplies of electricity. Despite the advantages that the galvanic battery possessed over the more clumsy frictional machine, these batteries were not very convenient for the production of large

supplies of electricity, and they were expensive things to maintain. Simple mechanical means can be devised to cause a magnet to move rapidly in the neighbourhood of a conductor and produce in it electric currents. This is the basic principle that underlies our modern dynamo.

Naturally these discoveries were thought of in terms of the fields of the magnets and currents, a point of view which, we shall see later, had important bearings on the theoretical progress of the subject.

We must now turn our attention to the other side of Faraday's work, which, equally important, did not attract so much attention at the time. It has been already stated that certain liquids act as conductors for the electric current, while other liquids do not. Pure water is a very bad conductor, while solutions of certain classes of substances are as good as metallic wires. These liquid conductors act in the same way as any other conductors; while a current is "flowing" through them they exhibit all the electrical and magnetic effects associated with current electricity. The quantitative laws that have been found good for other conductors also hold for these *electrolytes* as they are called.

They differ from other conductors, however, in the fact that the passage of electricity through them is accompanied by chemical changes in the electrolyte. Our best course will be to consider one concrete example. The diagram indicates an arrangement for sending a current through an

electrolyte. The batteries manufacture a supply of electricity which is conveyed along the wires attached to the *electrodes* dipping in the electrolyte. From the electrodes the current passes through the electrolyte and so completes the circuit.

If the electrolytic cell be filled with pure water then no current passes through it, because water is a non-conductor. The batteries will, however,

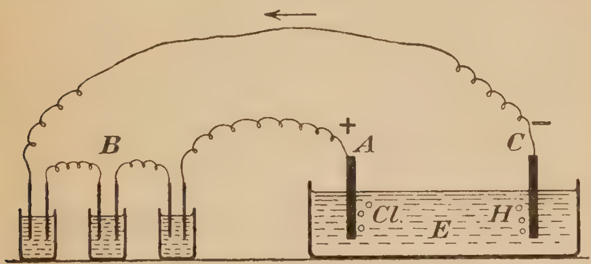

FIG. 3.—DIAGRAM OF ELECTROLYTIC CELL
E = Electrolyte; *B* = Battery; *A*, *C* = Electrodes;
H = Hydrogen bubbles; *Cl.* = Chlorine bubbles

maintain the electrodes in a charged condition, the one positively and the other negatively. If now we replace the water by an electrolyte a current at once begins to "flow." To make our example as useful as possible, we will select for our electrolyte a solution of a substance called hydrogen chloride. Chemists tell us that any specimen of matter is made up of innumerable small particles called molecules. Our solution then consists of many millions of hydrogen chloride molecules mixed up with water. Further, we know that

these molecules are made up of still smaller particles called atoms. The hydrogen chloride molecule is made up of one atom of the element chlorine united with one atom of the element hydrogen. The solution, as we are using it, is known as hydrochloric acid, or dilute spirits of salt to give it a common name.

Immediately the water is replaced by the hydrochloric acid a current begins to "flow." At the same time we observe that bubbles appear at the two electrodes. If we collect and examine these bubbles we find that those coming from the positive electrode are bubbles of the gas chlorine, and those from the negative electrode are hydrogen bubbles.

The hydrogen chloride molecules, with which we start, are a stable arrangement in which the two atoms composing them are firmly united together. Here we find them torn apart and sorted out so that the chlorine appears in one place and the hydrogen appears at another. At some stage in the process the molecules have been split up, which is only another way of saying that chemical action has taken place. The whole process is called *electrolysis*, and, as before noted, has important commercial applications.

The obvious first assumption is that the electric current has split up the molecules of the electrolyte, but reflection will indicate that this is not the only possible explanation. There are two stages in the electrolysis, first the hydrogen chloride has to be dissolved in water and then the current

passed through the solution. The splitting up, which does take place, could take place at either of these stages. From evidence derived from other sources we have to suppose that the obvious assumption is not the correct one. We now believe that the process of *solution* is accompanied by the splitting up of the molecule. In the case we have considered the only possible splitting will produce atoms of chlorine and atoms of hydrogen.

If we allow the current to flow for an indefinite time then we shall reach a stage where all the hydrogen chloride, with which we started, has been removed from the solution, as chlorine and hydrogen which appear at the electrodes only. Here we have the movement of particles of matter from all parts of the cell to the electrodes. We might imagine that the charged electrodes attracted these small particles of matter much in the same way that a charged body will attract tiny pieces of straw, but this would not account for the fact that the chlorine is sorted out from the hydrogen. The chlorine particles always move towards the positive electrode and appear there, and the hydrogen likewise always appears at the negative electrode. There is a selection about this attraction by the electrodes.

A very simple explanation of this selective action is given if we suppose that the atoms, as produced during solution, bear electric charges. If the atom of hydrogen is positively charged it will be attracted by the negatively charged electrode, and similarly a negatively charged chlorine atom

will be attracted by the positive electrode. In a solution, which is a mixture of oppositely charged particles, the introduction of charged plates will result in the sorting out of these particles.

Some such explanation as this we must offer. We cannot imagine that the solution contains atoms of hydrogen and chlorine as we know them, or there would seem no reason why they should not bubble off at any time, and from anywhere in the solution. If we associate an electric charge with these atoms, then we can suppose that the properties of the charged atoms allow them to act as we find they do.

This leads us to the idea of a new order of particle, differing from the atoms, as we know them, by the possession of an electric charge. To these particles is given the name IONS. Ions do not, as in the example we have considered, always consist of single, charged atoms. We may define them as atoms, or groups of atoms, which bear electric charges. Electrolytes are solutions that contain substances capable of producing these ions.

Getting back to our particular case we now explain what happens, as follows:—The act of solution splits up the hydrogen chloride molecule into two ions—an ion of chlorine bearing a negative charge, and an ion of hydrogen bearing a positive charge. These ions, when no current is passing, wander about in all directions in the solution. The introduction of the charged electrodes gives a definite drift to these wanderings, the chlorine

ions drifting to the positive electrode and the hydrogen ions to the negative electrode.

The solution itself is electrically neutral and so we have to suppose that the charges are not only opposite in nature but are equal also. When the ion reaches the electrode we imagine that it gives up its charge and becomes an ordinary atom as we know it. These ordinary atoms, produced at the electrodes, will then combine together to produce molecules of hydrogen and chlorine and appear as bubbles, each made up of billions of molecules.

Electrolysis consists, then, of the drift of charged particles across the electrolytic cell; but we recognise this drift by all the effects associated with an electric current. In the cell, at least, the "flow" of a current is the passage of charged particles.

Faraday investigated this process of electrolysis and discovered the laws by which it is regulated. We need not follow his work in any detail, but summarise it by saying that from the measurements he made it was possible to state the charge associated with an ion. These measurements indicated a wonderful simplification. It was possible to select the charge on the hydrogen ion as a unit and express the charges on all other ions as small multiples of this unit. No charge was ever found less than that on the hydrogen ion, and no fractional values were found for any other ions.

This suggests a limit to the possible magnitude

of an electrical charge, the limit being reached with the charge on a hydrogen ion. This charge we will call the *unit ionic charge.* All ionic charges are made up of a whole number of unit ionic charges, and at once arises the query, are all other electric charges so made up?

These conclusions seem to point to an atomic structure for electricity. Whatever electricity may be it has a discontinuous nature, at least as far as ions are concerned. Unfortunately such an avenue of inquiry was not investigated at that time. We can see very good reasons for this. It is always difficult to get beyond a preconceived idea. Previous work had directed attention away from the electricity itself into the fields of force. These fields of force, mapped out into lines of force, were so satisfactory that Faraday and his contemporaries felt no inclination to give them up.

CHAPTER VII

OTHER INFLUENCES

We must now leave the main stream of our story and explore into the surrounding regions, for so much that follows depends upon the influence that other sciences had upon the outlook from which the study of electricity was viewed.

Scientists of all ages have been faced with the same problems, to which they have attempted solutions more or less satisfactory at the time they were put forth. Among these problems two stand out in bold relief.

Man first encounters in his study of the world things which, like himself, occupy space. Such objects are grouped together and called *matter*. The earliest philosophers speculated as to the nature and structure of this matter. Early in this speculation, the idea that matter was continuous had to be given up. Such a conception could not be made to agree with common experience. Hence arose the vague idea of atoms from which has been derived, in the course of many centuries, our own more precise atomic theories of matter. Of this discontinuous structure for matter we have no doubt at the present time.

Next in importance to the matter itself is the movement of matter. As far as we ourselves are concerned we know that to move a material body from one place to another we have either to *push*

it or to *pull* it. Our muscles are capable of giving this push or pull, and we can construct machines of various kinds that will bring about the same effect.

We sum all this up by saying that in order to move matter we have to exert a *force* on it, and in a rather vicious circle define a "force" as that which moves matter. When we "apply" a force to a body, by means of our muscles or our machines, the driving instrument is always in contact with the body which is moved. We handle the body we are moving, or we "attach" the machine to it. The attachment may even be invisible, as when I blow a piece of paper off the table, but I know that in this case I make contact with the paper through the very real, but invisible, air. Whether the contact be direct or indirect, visible or invisible, all these movements necessitate that contact there shall be.

This application of a force to a body by contact presents no thought difficulty. It seems reasonable that, if I push a body, then it will move. There are, however, cases of matter in motion that are by no means so simple. There is, for example, the motion of the planets round the sun, the falling of an apple off the tree. Here there seems to be no contact direct or indirect. The earth whirls through empty space, the apple will fall in a vacuum. Consider also the action of a magnet on a piece of iron that is not touching it. We can imagine the piece of iron being mounted on wheels, when it will move along under the

"attraction" of the magnet just as if somebody or something were pushing it.

From the analogy of the mechanical forces which we or our machines can exert it is only natural to suppose that in these cases we are also witnessing the operation of some such "force." We say that the "force of gravitation" accounts for the motion of the earth and the fall of the apple, and that it is a "magnetic force" that moves the iron. We distinguish this class of action, where we can find no obvious connecting link between the force and the thing moved, as "attractions." The sun is said to attract the earth, the earth attracts the apple, and the magnet attracts the iron. We sometimes fail to realise that the giving of a name to a process is not an explanation, and it is a common occurrence to see the fall of the apple *explained* by saying that it is acting under the attraction of gravity, which is really only a short way of saying that it moves from the tree to the earth, and no explanation at all.

Here arises the second big problem of the study of the universe. How can a force be exerted across space without some intervening medium in which it can act? What is it that takes the place of the contact so necessary for the application of the commoner mechanical forces? What does "attraction" really mean?

We have numerous other familiar instances of a similar process. Something happens on the face of the sun, ninety odd millions of miles away, and

the effect reaches our eyes and we call it light. Between us and the sun we say there is only empty space. How then is this light effect transmitted across space?

This "action at a distance" is a very real thought difficulty. It was a greater puzzle in the days of Faraday than it is now. He and his predecessors and contemporaries could not conceive that one body could influence another unless there was some connecting medium between the two. Such a possibility was unthinkable, but nevertheless light came across empty space, the magnet acted through a vacuum, and the earth continued to roll on its course around the sun. Some explanation was necessary to satisfy the human mind.

An explanation is very easily found by simply filling empty space with some medium. It must naturally be a medium that differs from ordinary matter in some way, or it would have been detected. Hence we find philosopher after philosopher filling space with some hypothetical substance that will account for these "attractions." Such space-filling substances are called *æthers*. (This word is often spelt "ether," but there is a well-known substance which is known as ether, and it is better to retain the spelling "æther" for these hypothetical substances.) The nature and properties of these æthers have varied from time to time according to the nature of the problem to explain which they were invented. All space has been filled over and over again with æthers of

one sort and another, in fact it became almost a fashion at one time to invent an æther to explain any difficulty.

Up to the present time we have not been able to produce one scrap of direct evidence for the actual existence of any form of æther. This, however, neither proves an æther does not exist, nor does it detract in any way from the valuable place that æthers take in the advances of scientific thought. Without the æther, right or wrong, thought would have been at a standstill. Some such explanation was necessary for progress, and progress in science is not always movement in the forward direction, but it must be movement.

Of all these many æthers only one managed to hold its own against its opponents. The particular one was invented to explain the action of light. Light, whatever it was, was known to travel from the sun to the earth. It moved in straight lines and with a definite velocity. When the rays of light fall on our eyes they produce sensations that we call sight. When light falls on other bodies it may be absorbed, reflected or transmitted through the body.

Nearly four hundred years ago, the great Dutch physicist, Huygens, had offered an explanation of light based on the idea of a space filled with an æther in which light travelled by means of waves. It was not until the beginning of the nineteenth century that this idea was thoroughly established as a common belief. This particular æther was known as the *luminiferous æther*. It was supposed

to fill all space as far as the farthest stars from which light could come, and, in this mighty ocean, matter floated and was soaked in the æther, like pieces of blotting-paper floating in the sea.

Such a conception got rid of the difficulty of "action at a distance." What happens on the sun creates a disturbance in the neighbouring æther, and this disturbance travels through the æther till it reaches our eyes. We are supplied with a medium for transmission: the contact so essential for thought is provided by the æther.

At once arises the problem as to how the disturbances travel through the æther. The simplest possible explanation, and the one that best fits the facts, is that the propagation of light is of the nature of wave motion. We may seek an analogy in the waves in water with which we gain a familiarity from the time of our first conscious bath. Like all analogies it is imperfect, but it will serve very well to introduce the idea.

The waves that travel along the surface of water are, we know, composed of particles of water that move up and down. The water itself does not move along with the wave. If we place a cork on water agitated by waves, and prevent any air or water currents, then the cork moves up and down with the waves but retains a fixed average position. There is no drifting of the cork with the waves. The water is the medium that transmits the wave motion. Water we know is, like all other forms of matter, an elastic body. When agitated by waves we think of one particle

being displaced and dragging the next along with it and so on. The natural elasticity of the water tends to drag the displaced particles back to their original positions, and in this rush back they overshoot the mark and so continue oscillating backwards and forwards as long as the original cause of the disturbance continues to operate.

We are familiar also with waves in the air, such as those set up by musical instruments. The stretched wire that is struck on the piano communicates its motion to the air, and a wave passes away from the vibrating wire. In this case the particles of the elastic air do not swing up and down, but move backwards and forwards in the direction in which the wave is travelling.

These waves in water and in air are elastic waves. They are always accompanied by the movement of particles of the medium through which they are travelling. Such elastic waves are very common, and can take place in many different forms of matter, and, being familiar, it is no surprise that the first ideas of the waves in the luminiferous æther should be ideas of an elastic wave. The æther was thought of as an elastic medium. The action of the luminous body was such as to set up motion in the particles of this medium, which transmitted the motion to other particles. The æther, when light was passing through it, was in a state of vibration, much the same as the air is vibrating when transmitting a sound wave.

In water waves the moving particles swing round a fixed centre, in the air waves the movement is

to and fro in the direction in which the wave is travelling. To explain the laws of light it was necessary to imagine that the vibrations in the æther were in a plane at right angles to the direction of propagation. Such waves are called *transverse waves.*

We see then that at the time of Faraday's discoveries there was a mental background that consisted of a space filled with an hypothetical æther in which waves could be transmitted. This medium was looked upon as being some wonderful manifestation of an attenuated form of matter, and still retained the property of elasticity general to all forms of matter. The explanations that it gave of the phenomena of light were so satisfactory that very few doubts were expressed as to the possibility of its real existence.

CHAPTER VIII

MATHEMATICAL AIDS

We can now pick up the thread of our own particular story and follow it through one more advance.

Faraday's main contributions to the study of electricity were practical ones. He extended the observational side, in establishing the connection between electricity and magnetism. His observations were the basis of wonderful applications, and made the way possible for the next step.

His work also covered the investigation of the laws which regulated the observations he had made, and he speculated, more or less in a mechanical way, on possible explanations of the fields of force. These he thought of in terms of lines of force, which presumably operated in the luminiferous æther in some not too clearly indicated fashion. At least we know that "action at a distance," without an intervening medium, was entirely repugnant to the scientific outlook of his day.

In every science there arrives a stage in its history where observation and speculation must give way to the precise manipulations of mathematics. Mathematics is a necessity underlying every human activity. It is the only means available whereby we can be assured of precision. The express train in which we travel, to choose but one instance, is constructed to the design

calculated by the mathematicians, and, if they have divided by two when they should have multiplied, then the chances are that the next bridge over which we shall cross will be also a bridge from this world to the next.

As far as science is concerned mathematics is a very useful instrument. It is often a very difficult one to use, and many a scientist, of world fame, is unable to follow the mathematical treatment of his own subject. The speculations of the practical scientist are tested by the processes of mathematics. The test is often a crucial one, and may even lead to further practical progress along lines that are suggested by it.

Faraday's observations and laws were the starting-point of the famous Clerk Maxwell's mathematical treatment of electrical phenomena. On the basis of these facts he was able to raise a mighty structure. It is impossible here to enter into any detail of these mathematics, but we can state the conclusions that were arrived at as a result of this treatment.

Maxwell was able to show by strict mathematical reasoning the possibility that—

1. Electricity could travel through space by means of waves.
2. Every electric wave is associated with a magnetic wave, and conversely every magnetic wave is associated with an electric wave.
3. These waves were transverse waves.

To such waves as these the name *electro-magnetic waves* was given. We can see that such conclusions are a great advance on the theoretical side of the subject. It was a purely theoretical advance suggested only by the application of strict mathematical reasoning to the facts as known. It still remained for experiment to demonstrate that the possibilities could or could not be accomplished.

A further investigation enabled Maxwell to reach another surprising conclusion. Assuming the existence of these electro-magnetic waves, his calculations showed that the waves producing light were also electro-magnetic waves.

The electro-magnetic theory of light makes light and electricity manifestations of one and the same thing. This theory was able to offer very complete explanations of all that was known of electrical manifestations, other than electrolysis, which was left to explain itself. It was still a theory, there was no evidence that such waves could be produced. It had been noted previously that when a spark was obtained from a charged conductor the electrical changes that took place were in the nature of a vibration. The charge surged backwards and forwards during the change. Such a vibration might originate an electro-magnetic wave in the æther and, in 1888, Hertz was able to use this spark discharge and devise apparatus that would detect any waves that might be produced. His experiments were successful, in that electro-magnetic waves were produced and

detected across the space of a laboratory. Thus thirty-nine years ago was performed the first instance of wireless transmission; a crude experiment covering only a few feet, and suggested by the mathematical examination of electrical phenomena.

Wonderful as all these discoveries are, they contribute little to the main question as to what electricity is. We may know that it can originate waves, and we may learn how these waves travel through space, and yet be puzzled by the actual nature of that which produces them. We have emphasised the fact that the idea of electrical and magnetic fields, lines of force and such mechanical aids, directed attention away from the seat of the electrical charges. Space was already filled with a satisfactory luminiferous æther, and it was in this æther that explanations were sought. Around a charged conductor it was supposed that the æther was in a state of stress and strain, a state that under certain circumstances could be broken down, or changed, with the accompaniment of electrical and magnetic manifestations. In fact, so far was this idea carried, that the stresses and strains in the æther were considered to be the electricity itself. It has been pointed out that such a view is comparable with a statement that the oscillations of a suspension bridge, produced by a man walking over it, are not only the effects produced, but are also the man as well.

Still it is impossible to write too enthusiastically of this marvellous co-operation between experi-

mental fact and mathematical reasoning. It illustrates, in a striking manner, the methods by which science progresses. Without the aid of mathematical reasoning it is possible that electromagnetic waves would have been discovered accidentally, but the accident might not have occurred for hundreds of years. Once directed along the right lines the experimental work confirmed the theory in a few years.

We are, even to-day, only at the beginning of the usefulness of wireless transmission, but already it has conferred untold blessings on mankind. Used for signalling to ships at sea, and aircraft in the air, it has largely contributed to the safety of these methods of travelling. In the modern broadcasting of news, lectures and concerts it is entering into the lives of many millions daily. It is impossible to forecast what future developments will produce, but we may confidently look forward to marked advances, that may change the whole trend of human progress. All of which, be it noted, has been made possible, in our own time, by the combination of mathematics and experiment.

CHAPTER IX

WAVE MOTION

Before considering in any more detail the electromagnetic theory we must give a little more attention to wave motion. We have briefly stated some of the main facts previously, and now we must see if we can pick out the characteristics of this phenomenon.

In the first place it is necessary to have some kind of disturbance in order to produce a wave. On the sea the wind begins the movement of the water, some vibrating body sets the air in motion to originate sound waves, and the luminous body was supposed in some way to originate disturbances in the æther.

To produce a series of waves or a wave train the initial cause must be continued in a rhythmical fashion. Consider the vibrating wire on a piano. It moves forward and compresses the air in front of it—that is, the particles of air are squashed up in the direction of the movement of the wire. Then the wire moves back and the air particles surge back after it, owing to the elasticity of the air. A definite number of times per second this to-and-fro motion is continued, and the particles of air pass on their motion, forming a train of waves in the air.

Once we have a train of waves established in any medium, then, wherever we examine this wave train, we shall find the particles of the medium

repeating the rhythmical or periodic movements of the original motion. It does not matter what kind of vibration we consider, whether it is the swing of the water particles in a water wave, or the to-and-fro motion of the air particles in a sound wave. The motion, whatever it may be, will be repeated. If we could imagine one such wave train frozen stiff, and then we could examine it, we should find that at definite points along the train the same conditions would be repeated. In water waves we should reach crests of a wave at definite intervals as we followed the frozen train. Not only must the disturbance be periodic in time—so many times per second from one extreme to the other — but it must also be periodic in space—any phases of the change must be repeated at equal intervals along the train.

The characteristics of wave motion are a periodicity in both time and space.

There is no indication in this statement that any material particles move. Our examples have been chosen, so far, from wave motion in an elastic medium, where it is accompanied by actual movement of the particles of the medium. It is possible, however, to imagine a change that is periodic in space and in time that does not involve the motion of the medium through which it passes; and such change would certainly come within our definition of wave motion.

We must remember that wave motion is propagated with a definite velocity, which can be measured.

The periodicity in space suggests another wave measurement known as the *wave length.* The distance of one repetition to another is the wave length. At the crests of two consecutive water waves we have particles repeating the same phase of movement—that is, they are at the extreme limit of upward motion. The distance between two crests is the length of these waves. This length can obviously vary, and the variation will be noticed by the different effects produced.

We can, however, look at this from another point of view—namely, from the periodicity in time. The complete change, whatever it may be, is repeated a certain number of times in unit time. This number is called the *frequency* of the wave motion. The frequency and the wave length will have constant values wherever we make measurement in the wave train.

Velocity, wave length and frequency will obviously be related, and this relation is expressed in the following simple expression:—

$$\text{Frequency} = \frac{\text{Velocity}}{\text{Wave length}}$$

CHAPTER X

THE ELECTRO-MAGNETIC THEORY

The electro-magnetic theory at first seemed a triumph for the elastic æther, in conjunction with which it offered a reasonable explanation of electrical effects.

We have seen that electricity associated with a conductor produces electric and magnetic fields. In the same way that the magnetic field can induce magnetism, an electric field can induce electrical effects. This electrical induction is strikingly illustrated by the well-known sparking coil. This consists of a primary coil of wire, through which it is possible to send a current. The current is stopped and started again many times a second by a simple mechanical contrivance, so that the field of this coil will vary from nothing up to some certain strength many times per second.

Around the primary coil, and therefore in its field, is wrapped another coil, the secondary coil. At each make and break of the primary current —that is, at each variation of field strength—an induced current is produced in the secondary coil. A similar effect would be produced if initially we had a current "flowing" through the secondary coil. Its strength would vary with each variation of the inducing current. In the sparking coil itself the construction is so arranged that the

induced current is one of sufficient potential to give sparks across the gap in the terminal wires of the secondary coil.

Such induction leads us to the conclusion that, if at any point in an electro-magnetic field we cause variations of field strength to take place, then this variation will spread outwards, by induction from the centre of disturbance. If the variation be a periodic one, then we should find similar periodic changes occurring throughout the field, and the propagation of this periodic variation would be an example of wave motion.

Such a conclusion does not suggest the movement of any material particles; we only consider the variation periodically in time and space of field strength. We have only to imagine the field stretching indefinitely into space, to see that any change at one point will be propagated as a wave to all other points.

This conception does not necessarily do away with an æther, but it does make the assumption that it possesses elastic properties unnecessary. The retention of an elastic æther means the invention of many cumbrous assumptions as to its nature in order that it may fit the facts.

Considering the electro-magnetic waves that cause light, we recognise the existence of light of various colours. The variation in colour is explained as being due to a difference in frequency of the waves. White light derived from the sun can be split up into the seven colours of the rainbow, which we call the colours of the spectrum. At

one end of the spectrum we have red light, with a frequency of about four hundred billions per second, and at the other end the violet light, with about double that frequency. Using a musical analogy, we may say that visible light has a range of one octave of frequency.

The octave of high-frequency waves that produce light are not the only electro-magnetic waves that we know. We can explore the spectrum of light with our eyes, but we can also use a photographic plate for the same purpose. The photographic plate "sees" very differently than our eyes. Red light, for example, does not affect the plate, and still more remarkable is the fact that the plate is affected by waves of greater frequency than those of violet light. The plate detects electro-magnetic waves in a region, called the *ultra-violet* region, beyond the violet end of the spectrum. These ultra-violet rays have been traced for about seven octaves above the violet. At this point they join other rays that we call *X-rays*, and these extend for about eight octaves, where they join the latest rays that are given out by radioactive elements, the *γ-rays*, that extend for at least four octaves.

Exploration of the other end of the spectrum has revealed still more waves. First there is the *infra red* region of thermal radiations, which extend for eight octaves and then, after a gap of three octaves, we come to the Hertzian waves. It is the lower-frequency Hertzian waves that are used in wireless transmission.

Here, then, we have a wonderful simplification, in which various manifestations, recognised differently by our senses and our instruments, are seen to be manifestations of one and the same thing—electro-magnetic waves of various frequencies.

CHAPTER XI

THE ELECTRON

A SUMMARY of the position as it now stands—that is, towards the end of the nineteenth century—will be useful.

1. We know that electricity can be produced by friction, by chemical means, and other less important means.

2. Electricity will travel along certain solid substances as a current. No explanation of the mechanism of this current is offered.

3. Electricity will also travel through certain solutions, and here it is recognised that the "current" consists of the carriage of charges by particles called ions.

4. There are substances that apparently will not conduct.

5. Electro-magnetic influences can be propagated through space by wave motion.

6. Electric and magnetic forces are supposed to be connected in some way with strains and stresses in the luminiferous æther.

The study of non-conductors led to the next advance. Matter, in the state of a gas, is a very bad conductor, yet it was found that a charged body did slowly lose its charge when left in the air, even when leakage along the supports was made impossible. This led to very careful experiments, and it was found that the air and other gases could become good conductors under certain

circumstances. For example, if air, subjected to the influence of ultra-violet rays, was placed between two oppositely charged plates, then a current "flowed" from one plate to the other.

This obviously suggests the application of the idea of ions to gaseous conductors. The existence of charged particles in these gases was demonstrated, and they were said to be ionised. The passage of electricity through gases became an important matter, and it was examined under every possible condition. Striking results were obtained when the gas was under very reduced pressure. High potential currents passing through such gases gave rise to entirely new phenomena. From the negatively charged lead wire a stream of very minute, negatively charged, particles was shot out in straight lines with enormous velocities. These streams, first imagined to be wave manifestations, were proved to be streams of particles that possess mass like any other form of matter. It was found possible to measure this mass, which proved to be many times less than that of the hydrogen atom, hitherto supposed to be the lightest possible particle. The charge on these particles was also found, and it was identical with the unit ionic charge, previously described.

The name *electron* was given to these particles, and further research showed that not only could they be derived from all forms of matter, but that, from whatever widely different sources of matter they came, they were identical. They were obtained by many other means than that of the

discharge tube. The discovery of radioactivity contributed another supply of electrons, derived this time from the actual atoms of the radioactive elements. The atom, thought to be structureless, was in part made up of electrons. As information accumulated about these electrons, the idea that they were minute particles bearing a charge had to be given up, and the electron was looked upon as being the very charge itself. It was the atom of electricity, the logical outcome of Faraday's work on electrolysis.

The fact that the electron was part of an electrically neutral atom suggests that, also within the atom, is another particle that is a positive charge. Evidence of the existence of this particle has been obtained, and it is known as the *proton*. Electricity consists, according to this view, of negative and positive atoms—the electron and the proton—and combinations of these two compose the atoms which make up matter as we know it.

Many suggestions have arisen as to the probable arrangement of the electrons and protons within the atom. It has been practically established that it is the proton, or groups of protons, that account for the mass of the atom. Compared with the proton the electrons are of almost negligible mass. The atom possesses a nucleus consisting of protons and electrons mixed together, and around this nucleus other electrons are grouped. The suggestion that is meeting with most favour now, is that the electrons outside the nucleus are travelling around it in orbits, much in the

same way that the planets move around the sun.

We may now apply these ideas to the explanation of electrical manifestations that we have described. Matter consists of atoms made up of electrons and protons. We can easily imagine that any atom could lose one or more electrons, and the residue would then be a positively charged one. If by any means we can accumulate either electrons or positive atomic residues on a conductor, then we should have associated with the accumulation all the effects of an electric charge. A charged conductor is, then, but an accumulation of either electrons or atomic residues, produced by the means taken to charge it.

The protons, in virtue of their mass, we consider to be less capable of motion than the electron. Electric currents are therefore looked upon as the drift of electrons. These may either be free streams of electrons, as in the discharge tube, or they may be associated with ions, as appears to be the case in electrolysis, or again they may just wander from atom to atom, as would explain the current in a wire. At any rate a current of electricity is the manifestation associated with the movement of an electric charge.

With electrons revolving round a central nucleus in the atom, we can also see possibilities of disturbances arising in these journeys that might be made to account for the production of the electro-magnetic waves that have been shown to exist in space.

CHAPTER XII

RELATIVITY

The theory of Relativity developed in the last twenty years has important bearing on electricity and must receive brief mention.

It is the latest attempt in an age-long inquiry. From the earliest time that man began the serious study of the Universe, he has always been impressed with the magnitude of the task. There seems so much to be done, so many varying happenings, that the task is apt to appear impossible. The mind of man is finite, we say, and within this finite compass we try to compress what may be the infinite.

Not only are we confronted with the problems on the surface of our own earth, but there is the wider field of the stars and other heavenly bodies which we can but imagine are all related in some way or other. Then, once we really get to grips with any one problem, we seem to at once complicate it. What appeared simple becomes complex. We have seen, for example, how the simple little experiment of rubbing amber has been extended to a vast science with ramifications into almost every branch of knowledge.

Man might well have given up the task but for one mental qualification in the nature of a belief. The earliest philosophers, and the generations that have followed them, believed that,

beneath all this complexity, there was a simplicity. If only this simple explanation could be found then the finite brain of man could understand it and be satisfied. The history of philosophy is the story of the attempts to reach this simplification.

At the beginning of the present century the Universe, as then understood, consisted of matter occupying space, matter which we have seen is composed of atoms of electricity. This matter was supposed to obey the laws of a geometry, the foundations of which were laid by the famous Euclid. The Euclidian geometry attempted to simplify all the space relations of matter by making a few assumptions, believed to be true, and logically following their results.

Besides matter there were the great "forces of nature." There was the force of gravity which kept the planets in their courses, which regulated the positions of all the heavenly bodies, which kept our own bodies on the face of the Earth as it whirled through space. A law of gravitation was deduced by means of which it was possible to calculate and forecast these movements, but no satisfactory explanation of how the "attraction of gravity" worked was ever made. Attempts to modify the luminiferous æther so as to account for gravitation were failures. Gravitational force had to be left in splendid isolation.

The other forces of nature—the various manifestations of energy—were explained, as we have seen, by electro-magnetic waves operating in the luminiferous æther. This æther necessitated some

very cumbrous assumptions, and all attempts to demonstrate its actual existence failed.

Finally there was the conception of time. Not only did matter exist in space, not only did forces act on the matter, but the existence and the action took place in time. It seemed as if there was absolute space apart from absolute time. Time was a separate conception, and one could think of space and force without any reference to time, provided one thought in the geometry of Euclid.

The new Theory of Relativity combated, in the first place, this separation of time from space. It held that they were mutually dependent and that it was incorrect to think of one without the other. The theory was put forward, first in a special form, by Einstein in 1905, and in a generalised form ten years later. It set out to give to space a new structure, and in this structure the factor of time is included as well as the three dimensions of the older geometry of space. According to this point of view a point in space is not fixed by reference to three planes, but a fourth reference to a plane of time is also necessary.

It is well to give a warning here. *It is impossible to form a mechanical mental picture of this new four-dimensional space.* We can conceive of its meaning, but we cannot picture it. If we think of a very flattened individual who had lived all his life on a plane as smooth as a sheet of polished glass, who had never climbed a ridge, never moved in any other way than along the surface of this plane,

we can see that, for him, the Universe would have measurements only of length and breadth. The mind of such an individual could not possibly form a picture of a mountain, but it could form a conception of volume. Our difficulty is a similar one, in four-dimensional space. We may conceive of its existence, we may state the mathematics and geometry of such space, but we cannot picture it. We can think *of* it but not *in* it.

Relativity has been very well called a "generalised geometry," of which the older geometry was only a special case—a simplified and ideal geometry in which time and space were artificially separated. The proper understanding of this new space is reached only by the aid of advanced mathematics, but the main results of the theory may be stated, as the conclusion that everything that happens in the Universe goes on as if there were no æther. With this conception of space it has been said that "A being that was born without any one of his five senses, but with unlimited geometrical reasoning powers, could deduce the general nature of the actual world without any experience of reality: he would anticipate that landslides, earthquakes, thunderstorms and auroræ would occur."

On a geometrical basis a concise explanation of the forces of nature is offered by Relativity. These natural forces—gravitational and electromagnetical — become "geometrical necessities." The universe, as conceived in this way, contains no "forces"; events occur because that is the way they should occur, and it is not necessary

either to enlist the aid of an æther, or to consider such a thing as action at a distance.

In the Euclidian world parallel lines never meet because that is one of the laws of Euclidian geometry. In the world of four-dimensional space the planets revolve round the sun because that is one of the geometrical laws of this space. If we set a ball rolling on a curved surface, then its path is determined by the geometry of that surface. In a similar fashion Einstein and his followers assume that space may be curved and crumpled. It is this curving space that accounts for all that we have been accustomed to attribute to the action of "forces." It is possible to treat this curving space mathematically, and it was found that such calculations did not agree in all cases with those made on the older ideas. Thus it was possible to put the idea to the test of experiment, and the results of these experiments are entirely in favour of Relativity.

It is impossible to go into this fascinating theory in any more detail here. We must however realise that the workers in this field have made the "forces of nature" mathematically intelligible. The unique force of gravitation and the array of electro-magnetic manifestations have been reduced to geometrical necessities, which, even if difficult to manipulate, do really carry the simplification one step farther, a simplification that has been hailed, perhaps prematurely, as the final one.

CHAPTER XIII

THE QUANTUM THEORY

We have seen that the Theory of Relativity had put forward a more or less simple explanation of all the "forces of nature." Events happen because that is what would be expected in the space that has length, breadth, height and time.

Still it is not a complete explanation of the Universe. It would not suggest the difference between positive and negative electricity or give an atomic structure to electricity. Neither does it give any light on the cause of the radiations that we recognise as electro-magnetic waves.

The subject of radiation has received considerable help from a theory which was first put forward in 1900, and known as the Quantum Theory. Briefly, it may be described as the introduction of the idea that not only are the physical substances, that take part in any action, divisible into ultimate atoms, but that the physical process itself is also discontinuous. Physical processes are considered, by this theory, to take place by a series of "jumps" as it were. The unit jump, the atom of action, can be called the *unit quantum of energy or action.* According to this idea, for example, the emission of energy, in the form of heat, that occurs from the surface of a hot body, takes place by definite quanta of energy.

Einstein applied this theory to a consideration of the radiations we call light, and was led to

believe that light was transmitted in a series of definite "bundles" of energy, a view that has had to be very much modified. The general idea underlying the theory has been used to clear up very many difficulties in a reasonable way.

Bohr applied the Quantum Theory to a consideration of the atomic model in 1913, with results that are very striking. It had been observed, in the middle of the nineteenth century, that each of the chemical elements had a characteristic spectrum. This spectrum was composed of definite lines and bands of colour, corresponding to the electro-magnetic waves of various frequency that were originated by the atom when excited by high temperature. The spectral lines of the element hydrogen displayed a comparatively simple numerical relationship that had remained unexplained.

The hydrogen atom consists of one proton and one associated electron. Bohr assumed that the electron revolved around the proton. Now, according to older ideas, this planetary electron could take up any number of orbits round the nucleus, as can the planets round the sun. In the light of the newer theories, Bohr was able to assume that this was not the case for the swiftly moving electron. He showed that there were only certain very definite orbits that could be followed, and that the dimensions of these were related to the unit quantum of energy. While pursuing any one of these orbits the electron would not be emitting energy, but if it were possible to imagine the

electron suddenly "jumping" from one orbit to another, then emission of energy would occur during the change. He was able to calculate the possible orbits in a hydrogen atom, and forecast from them the position of the lines in the spectrum—that is, the frequencies of the electromagnetic waves that the "jumping" electron would produce. The introduction of elliptical orbits, where Bohr had considered only circular ones, complicated the mathematics, but made the theoretical calculations so close to the experimental measurements as to provide striking confirmation of Bohr's assumptions.

Further than this we cannot go. Indeed it is only just to emphasise the fact that these theories are yet in their infancy. Their complete significance and the modifications that they will undergo will only be seen in the future. We can, however, feel that the work is on the right lines towards the final and complete explanation of the Universe which will satisfy the finite mind of man.

CHAPTER XIV

CONCLUSION

We set out to tell the story of electricity, and we have traced its history from the earliest speculations down to the latest developments that are occurring in the wide field it occupies to-day. The story has shown how the study of electricity has solved many of the problems of science. It has given a simple structure to matter and joined up with other manifestations in what has been claimed to be a final explanation of the forces of nature.

We may have our doubts of that finality. It is only a few years ago that we felt certain of the finality of our ideas about matter, but our indestructible atoms have been shown to be miniature solar systems. We may expect surprises in the future, surprises with equally revolutionary results, for again it must be said that, much as we know of electricity, we do not yet know that which will answer the question "What is it?"

The atoms of electricity may yet reveal a structure, and stagger us again with the wonder and the magnitude of the Universe.

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